

Research Article

Groundwater Prospecting in Coastal Sedimentary Terrain Using 2D ERT and GIS: A Case Study of Ikot Abasi, Nigeria

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Abstract

Groundwater demand in Nigeria's coastal regions is rising, yet subsurface assessment is complicated by heterogeneous sediments and tidal influences. This study applies an integrated approach combining 2D Electrical Resistivity Tomography (ERT), Vertical Electrical Sounding (VES), Geographic Information Systems (GIS), and remote sensing to delineate aquifer zones and assess groundwater quality in Ikot Abasi, Akwa Ibom State. ERT data were collected along three 200 m profiles using a Wenner-Schlumberger array and inverted with Res2Dinv. Twelve VES points provided complementary hydrogeological parameters including transmissivity and hydraulic conductivity. GIS and remote sensing datasets (SRTM DEM, Sentinel-2 imagery, drainage networks, and land cover maps) were used to georeference profiles, analyze terrain influence, and correlate resistivity anomalies with geomorphology. Results revealed three main subsurface units: shallow conductive clayey horizons (<50 Ωm), intermediate silty sands (80-800 Ωm), and deeper resistive aquifer zones (>1000 Ωm) with transmissivity up to 65 m^2/d . Water quality analyses showed most parameters within WHO standards, although elevated calcium, magnesium, and iron suggest geogenic enrichment from ferruginous sands. The study demonstrates that integrating ERT with GIS and remote sensing improves interpretation of aquifer distribution and groundwater quality in complex deltaic settings. This multidisciplinary workflow provides a more reliable basis for groundwater development and sustainable resource management in Nigeria's coastal sedimentary terrains.

Keywords

2D Electrical Resistivity Tomography (ERT), Coastal Sedimentary Terrain, GIS, Python Geophysics Remote Sensing, Subsurface Characterization

1. Introduction

Electrical Resistivity Tomography (ERT) is widely used to image subsurface conditions by measuring spatial variations in electrical resistivity. It has proven effective for delineating stratigraphic layers, locating aquifer horizons, assessing foundation stability, and detecting subsurface anomalies [16, 27]. In

sedimentary terrains such as Akwa Ibom State, where unconsolidated sands, clays, and laterites occur, resistivity techniques are especially valuable for groundwater exploration. However, interpretation can be challenging because lithological heterogeneity, tidal influence, and seasonal flooding often obscure

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clear resistivity patterns [31, 10]. Recent advances show that combining geophysical data with Geographic Information Systems (GIS) and remote sensing can enhance interpretation. GIS supports spatial correlation between resistivity anomalies and surface features such as elevation, drainage, and land cover, while satellite imagery (e.g., Sentinel-2, Landsat) provides contextual information on geomorphology and surface conditions [21, 33]. Studies have successfully applied these tools separately, but their combined use in deltaic environments of southern Nigeria remains limited.

In the Niger Delta Basin, where Ikot Abasi is located, groundwater investigations face added complexity. The Benin Formation comprises unconsolidated sands interbedded with clays and lateritic horizons, producing variable hydrogeological properties [7, 19]. Seasonal inundation and proximity to the Atlantic Ocean further complicate aquifer evaluation by introducing salinity gradients and fluctuating water tables [20, 22]. Previous works [20, 11, 30] provide valuable insights into aquifer conditions but seldom integrate high-resolution resistivity imaging with geospatial datasets.

This study addresses that gap by combining 2D ERT and

VES surveys with GIS and remote sensing to improve subsurface zonation in Ikot Abasi. Specifically, it aims to (i) delineate aquifer zones and clay barriers using resistivity imaging, (ii) derive hydrogeological parameters from VES for aquifer evaluation, (iii) integrate geospatial data to strengthen interpretation of lithological variability, and (iv) assess groundwater quality against WHO standards. By adopting this integrated workflow, the study seeks to improve accuracy in groundwater assessment and provide practical insights for water resource development in coastal sedimentary environments. [17, 23, 28].

Study Area and Geological Background

Ikot Abasi is located in the southwestern part of Akwa Ibom State, within the coastal sedimentary basin of south-eastern Nigeria, specifically between latitudes $4^{\circ}30' - 4^{\circ}40'N$ and longitudes $7^{\circ}30' - 7^{\circ}45'E$. It forms part of the eastern Niger Delta and is characterized by a low-lying terrain, with elevations generally below 50 meters. The area is drained by a network of rivers and creeks linked to the Imo and Qua Iboe River systems [15, 12, 13].

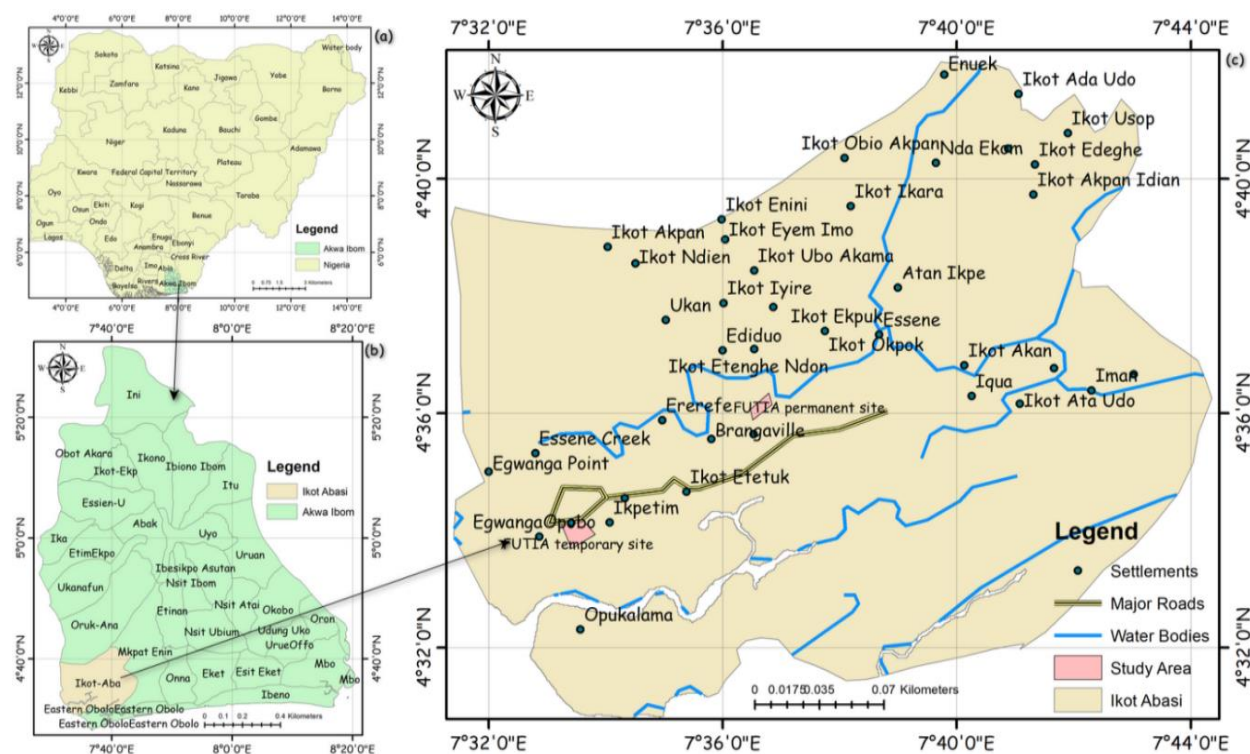


Figure 1. Location Map Showing the Research Area.

Compiled in August, 2024 using GIS datasets (WGS 1984, UTM Zone 32N); displays Settlements, water bodies, roads, and delineated study boundary within Ikot Abasi LGA, Akwa Ibom State; approximate scale 1:70,000

Geologically, Ikot Abasi lies within the Benin Formation of the Niger Delta Basin. This formation consists mainly of unconsolidated to poorly consolidated sands, silts, and intercalated clays of Miocene to Recent age [25, 7]. The dominant lithological unit's unconsolidated sands and silts exhibit moderate to high

resistivity and serve as potential aquifer zones [3]. In contrast, marine and alluvial clay deposits are more conductive and function as aquitards or aquicludes. Lateritic horizons and organic-rich layers, such as peat zones, may also cause localized resistivity anomalies [12]. The porous nature of the sediments

contributes to the area's high groundwater potential, supporting the presence of extensive shallow aquifers [9, 1]. These features make Ikot Abasi ideal for hydrogeological exploration and water resource development [19]. The region's sedimentary environment is shaped by fluvio-deltaic and marine processes, which, combined with seasonal flooding and proximity to the Atlantic Ocean, create variable soil saturation and salinity gradients. These factors can significantly influence geoelectrical readings.

Given this complex setting, Electrical Resistivity Tomography (ERT) is particularly suitable for mapping subsurface features [5, 4]. It aids in delineating aquifer geometries, lithological discontinuities, and potential contaminant plumes [2]. Previous ERT applications in similar coastal areas have successfully identified stratigraphic layers, buried channels, and saltwater intrusion zones [18, 14], affirming Ikot Abasi's suitability for such investigations.

2. Methodology

2.1. Electrical Resistivity Tomography (ERT)

Three 200 m profiles were surveyed using the Wenner-Schlumberger array with 64 electrodes at 5 m spacing. A Syscal R1 Plus resistivity meter recorded apparent resistivity values, which were stored in .dat and .csv formats. The Wenner-Schlumberger configuration was selected for its balance of vertical resolution and lateral coverage, making it suitable for imaging heterogeneous sediments of the Niger Delta. Data preprocessing involved removing noisy readings and outliers. Inversion was carried out using Res2Dinv, generating 2D resistivity models for each profile. Resistivity sections were interpreted in terms of lithology and hydrogeological significance, guided by published resistivity ranges for sands, clays, and lateritic soils.

2.2. Vertical Electrical Sounding (VES)

In addition to ERT, twelve VES points were occupied across the study area to complement resistivity imaging with depth-dependent parameters. The Schlumberger array was employed, and apparent resistivity curves were interpreted

using WinResist software. From the interpreted layer parameters, hydrogeological properties were estimated: Longitudinal conductance (S) - aquifer protective capacity, Transverse resistance (T) - aquifer transmissivity potential, Hydraulic conductivity (K) - groundwater flow capacity and Transmissivity (Tr) - total aquifer productivity. These parameters allowed quantitative comparison of aquifer conditions across sites and validation of ERT interpretations.

2.3. GIS and Remote Sensing Integration

The Geospatial datasets were used to provide spatial context for the geophysical data: Digital Elevation Model (SRTM, 30 m) - terrain analysis, drainage patterns, and profile georeferencing. Sentinel-2 imagery (10 m resolution) - land use/land cover (LULC) classification to relate resistivity zones to surface geomorphology. Drainage network and settlement data - extracted from existing topographic maps and updated in QGIS. ERT profiles and VES points were georeferenced to WGS 1984, UTM Zone 32N, and overlaid on DEM and LULC maps. Spatial correlation was then performed to examine how aquifer zones align with geomorphic features (e.g., low-lying floodplains, sandy ridges).

2.4. Groundwater Sampling and Analysis

Five borehole water samples were collected across the study area and analyzed for physicochemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), alkalinity, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), and major ions (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , HCO_3^- , SO_4^{2-} , Fe^{2+} , Mn^{2+}). Standard procedures recommended by APHA (2017) were followed. Results were compared with WHO (2017) drinking water guidelines to assess suitability.

3. Results and Discussion

(a) Vertical Electrical Soundings Parameters

Table 1. Summary of Hydrogeological Parameters from Vertical Electrical Soundings (VES).

VES Points	Apparent Resistivity (Ωm)	Depth (m)	Thickness (m)	Longitudinal Conductance (Ω^{-1})	Transverse Resistance ($\Omega\cdot\text{m}^2$)	Hydraulic Conductivity (m/d)	Transmissivity (m^2/d)
VES 1	0.497	39.500	25.400	51.107	12.624	0.691	17.545
VES 2	12.000	50.100	43.300	3.608	519.600	0.681	29.466
VES 3	1.930	109.000	95.200	49.326	183.736	0.689	65.637
VES 4	1.480	89.600	72.200	48.784	106.856	0.690	49.809
VES 5	1.030	63.800	58.400	56.699	60.152	0.690	40.312

VES Points	Apparent Resistivity (Ωm)	Depth (m)	Thickness (m)	Longitudinal Conductance (Ω^{-1})	Transverse Resistance ($\Omega\cdot\text{m}^2$)	Hydraulic Conductivity (m/d)	Transmissivity (m^2/d)
VES 6	3.310	49.100	24.700	7.462	81.757	0.688	16.999
VES 7	0.263	78.400	71.100	270.342	18.699	0.691	49.128
VES 8	0.752	47.200	40.400	53.723	30.381	0.691	27.897
VES 9	2.000	58.900	47.000	23.500	94.000	0.689	32.402
VES 10	2.940	90.800	79.700	27.109	234.318	0.689	54.878
VES 11	1.480	105.000	98.500	66.554	145.780	0.690	67.952
VES 12	1.330	113.000	96.900	72.857	128.877	0.690	66.862

The findings from the VES survey conducted and its analysis focuses on the parameters of apparent resistivity, depth, thickness, longitudinal conductance, transverse resistance, hydraulic conductivity, and transmissivity as shown in Table 1.

In Electrical Resistivity Tomography (ERT), the inverted 2D resistivity models provide a continuous image of the subsurface lithology and aquifer framework across the study area. The sections revealed three dominant geo-electrical layers: Shallow conductive units ($<50\ \Omega\text{m}$) interpreted as clay, lateritic clay, or water-saturated topsoil horizons. These layers are discontinuous, varying in thickness from 3-10 m, and act as aquitards. While they restrict vertical infiltration, they also provide partial protection against downward migration of contaminants. The high conductivity of these layers is consistent with the dominance of clayey sediments within the upper horizons of the Benin Formation. Intermediate resistive horizons ($80\text{--}800\ \Omega\text{m}$) which correspond to fine- to medium-grained sands and silty sands. These horizons are more laterally extensive, occurring at depths between 10-30 m, and form the primary semi-permeable zones. Although their resistivity values are lower than coarse sands, their thickness indicates that they may host moderate-yield aquifers. Deep high-resistivity zones ($>1000\ \Omega\text{m}$) associated with coarse sand and gravel formations. These aquifers, often encountered at depths of 30-50 m, display higher transmissivity and permeability. Their lateral continuity suggests the presence of regional groundwater reservoirs that are capable of sustaining abstraction for both domestic and agricultural purposes. The geometry of these aquiferous layers is highly variable, with pinch-outs and truncations that suggest structural or depositional controls. In some cases, thick aquifer sands are capped by clay lenses, resulting in confined aquifers with potentially better water quality due to natural filtration.

The VES data complement the ERT sections by providing depth-specific information about aquifer characteristics. Apparent resistivity values varied widely across the twelve stations, ranging from as low as $0.263\ \Omega\text{m}$ at VES 7 to as high as $12.0\ \Omega\text{m}$ at VES 2. Low resistivity zones ($<1\ \Omega\text{m}$) such as VES 1 ($0.497\ \Omega\text{m}$) and VES 7 ($0.263\ \Omega\text{m}$) indicate clay-rich or highly water-saturated formations. These lithologies are

typically unfavorable for groundwater storage due to their poor permeability and highwater retention capacity. Such units act as aquitards, reducing transmissivity and limiting the usefulness of these zones for sustainable abstraction. High resistivity values ($\geq 10\ \Omega\text{m}$), observed at VES 2, indicate sand and gravel formations with favorable groundwater potential. This zone is interpreted as a productive aquifer with good storage and transmissivity, as shown in Figure 2.

Moderate resistivity values ($1.03\text{--}3.31\ \Omega\text{m}$) observed at VES 3, VES 4, VES 5, VES 10, and VES 12, suggest the presence of silty sands and mixed sediments. These materials have moderate porosity and permeability, providing intermediate groundwater potential. Aquifer depths ranged from 39.5 m (VES 1) to 109 m (VES 3), with aquifer thicknesses between 58 m and 113 m. The deepest and thickest aquifers (VES 3 and VES 12) represent more extensive groundwater reservoirs, which are likely to be more productive and less susceptible to seasonal depletion or surface contamination. In contrast, shallow aquifers such as VES 1 are more vulnerable to pollution from surface activities, especially in areas with poor sanitation or agricultural runoff.

Hydraulic conductivity values ranged narrowly between $0.690\text{--}0.700\ \text{m/d}$, suggesting relatively uniform permeability across most VES points. This consistency indicates that the aquifers are predominantly composed of sandy sediments that allow stable groundwater movement. The implication is that groundwater flow in the study area is predictable, with minimal localized variations in permeability.

Transmissivity values, however, displayed greater variation, ranging from $16.9\ \text{m}^2/\text{d}$ (VES 6) to $65.6\ \text{m}^2/\text{d}$ (VES 3), as shown in Figure 3. High transmissivity values signify aquifers with greater capacity to transmit water, making them more suitable for exploitation. VES 3 and VES 12 are therefore considered the most productive groundwater zones. Conversely, VES 6, with low transmissivity, may not sustain long-term pumping without risks of drawdown or depletion. Overall, the VES results suggest a tripartite zonation of groundwater potential: Low potential zones (VES 1, VES 6, VES 7) dominated by clay-rich formations. Moderate potential zones (VES 4, VES 5, VES 8, VES 9, VES 10, VES 11) consisting of silty

sands. High potential zones (VES 2, VES 3, VES 12) associated with thick, laterally continuous sand and gravel horizons.

However, the integration of the resistivity results with geospatial datasets enhanced interpretation of the hydrogeological framework. DEM analysis revealed that the most productive aquifer zones coincide with geomorphic ridges and moderately sloping terrains, whereas clayey, low-resistivity

horizons were associated with floodplains and poorly drained depressions. Land use/land cover (LULC) mapping from Sentinel-2 imagery further indicated that high groundwater abstraction areas overlapped with cultivated and built-up zones. This finding highlights the dual challenge of resource availability and vulnerability, as anthropogenic activities can increase the risk of groundwater pollution.

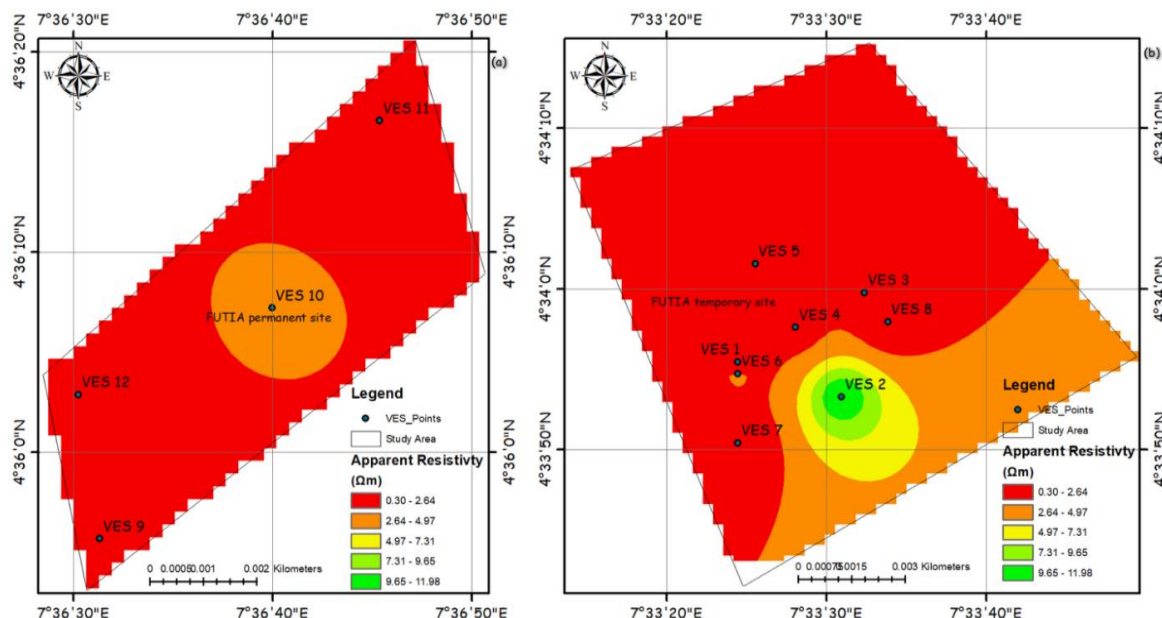


Figure 2. Apparent Resistivity Maps Showing Distribution from VES Data in the Study Area.

Generated August 2024 using 2D VES Data and GIS interpretation (WGS 1984, UTM Zone 32N), displays apparent resistivity variation across study area, approximate 1:25,000)

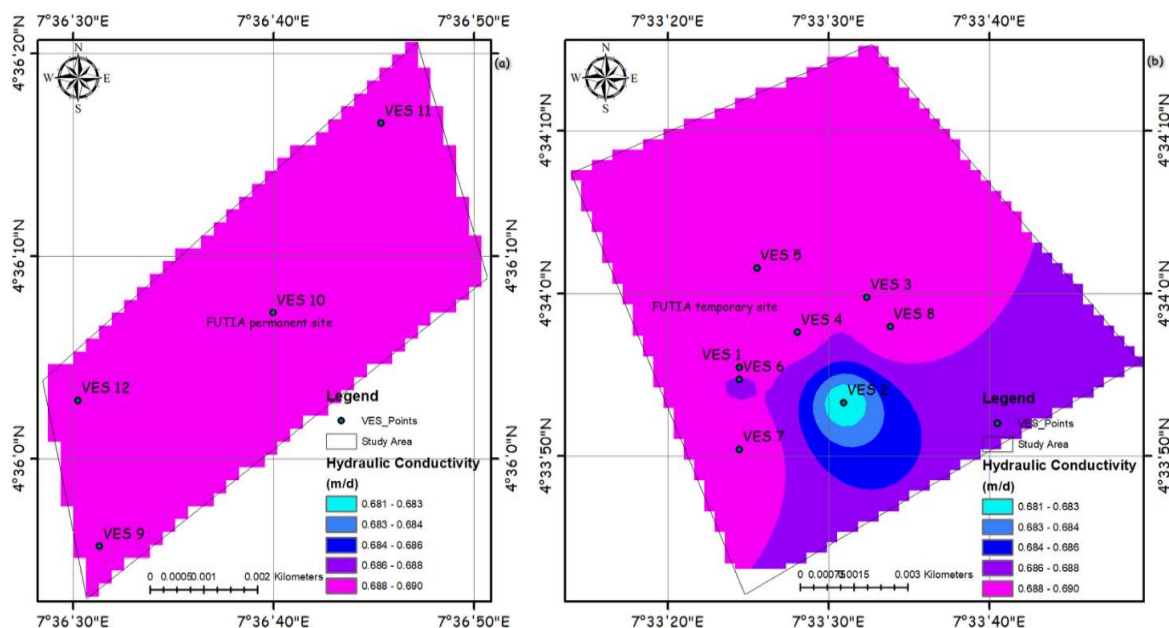


Figure 3. Hydraulic Conductivity Maps Derived for VES Data in the Study Area.

Created August 2024 using estimated Hydraulic Conductivity values from geo-electrical interpretation (WGS 1984, UTM Zone 32N), illustrates spatial variation in hydraulic conductivity across study area, approximate 1:25,000

(b) Physicochemical Analysis Of Water Samples

A five different water samples namely: A, B, C, D, and E were gathered from different boreholes situated within the study areas. The result showing the concentration of anions and cations present in the water samples, are shown in [Table 2](#).

Table 2. Comparison of Water Quality Parameters Against WHO Standards [28].

S/N	Parameters	A	B	C	D	E	WHO (2017)
1	pH	6.16	6.81	6.37	7.10	6.82	6.50 - 8.50
2	Electrical conductivity ($\mu\text{S}/\text{cm}$)	257.00	34.70	45.70	109.00	89.50	500.00
3	TDS (mg/L)	168.00	18.80	23.20	77.60	46.60	500.00
4	Alkalinity (mg/L)	45.00	30.00	35.00	35.00	20.00	200.00
5	DO (mg/L)	3.20	3.00	3.10	3.20	3.00	-
6	BOD (mg/L)	2.64	2.82	2.42	2.18	2.62	2.00
7	COD (mg/L)	5.48	5.64	4.84	4.36	5.24	10.00
8	SO_4^{2-} (mg/L)	2.13	1.24	1.42	2.02	2.12	250.00
9	Cl^- (mg/L)	46.15	17.75	17.76	39.05	28.40	250.00
10	HCO_3^- (mg/L)	54.90	36.60	42.70	42.70	24.40	200.00
11	Na^+ (mg/L)	29.90	11.50	11.50	25.30	18.42	200.00
12	K^+ (mg/L)	8.218	6.32	6.32	11.35	8.15	200.00
13	Ca^{2+} (mg/L)	140.00	180.00	44.00	92.00	100.00	7.50
14	Mg^{2+} (mg/L)	85.05	65.61	26.73	55.89	60.75	50.00
15	Mn^{2+} (mg/L)	0.32	0.25	0.42	0.632	0.38	0.50
16	Fe^{2+} (mg/L)	0.35	0.32	0.33	0.324	0.38	0.30

The hydrochemical analysis of groundwater samples across the study area reveals a range of physico-chemical parameters that provide insights into both the quality of water for human consumption and the geochemical processes influencing its chemistry. The pH values, which ranged from 6.16 to 7.10, present a slightly variable condition of acidity to near neutrality. Boreholes B, D, and E were well within the [29, 28] acceptable limits (6.5-8.5), indicating chemically stable and potable water, while boreholes A and C recorded values slightly below the permissible lower bound. Such mildly acidic groundwater conditions are significant, as acidity enhances the dissolution and leaching of metallic ions including lead, copper, zinc, and iron from pipelines or aquifer minerals [8, 26]. This process not only compromises plumbing infrastructure but also raises potential human health risks such as gastrointestinal irritation, kidney dysfunction, and long-term organ damage.

Electrical Conductivity (EC) values were found between 34.70 and 257.00 $\mu\text{S}/\text{cm}$, which fall comfortably below the WHO threshold of 500 $\mu\text{S}/\text{cm}$ for potable water. These comparatively low EC readings suggest a limited interaction between infiltrating groundwater and aquifer minerals,

pointing to a relatively pristine aquifer system free from substantial anthropogenic input. In groundwater quality studies, EC serves as a rapid indicator of ionic concentration; elevated values exceeding 500-1,000 $\mu\text{S}/\text{cm}$ are often diagnostic of contamination from agricultural leachates, industrial effluents, or saline intrusion [11, 21, 15]. Thus, the observed low EC levels in this study area signify a minimal geochemical load, reflecting a groundwater environment that has not yet been adversely impacted by human activities.

The concentration of Total Dissolved Solids (TDS) spanned 18.80 to 168.00 mg/L, which is far below the WHO permissible limit of 500 mg/L. This outcome strongly underscores the suitability of the groundwater for domestic, agricultural, and industrial usage. The moderate presence of TDS is linked to natural water-rock interactions, particularly the weathering of silicate and carbonate minerals, as well as minor anthropogenic inputs such as agricultural residues [32, 6]. Since TDS remains within acceptable standards, the water can be considered fresh and not saline, a factor highly advantageous for irrigation and household consumption without extensive treatment.

The Dissolved Oxygen (DO) content ranged from 3.00 to

3.20 mg/L, which is notably low compared to typical standards for potable water (above 5 mg/L). Low DO levels may be symptomatic of organic matter decomposition and microbial respiration within the aquifer system. Such oxygen-deficient conditions can promote reducing environments that encourage the mobilization of iron and manganese into solution. The Biochemical Oxygen Demand (BOD) values, which ranged from 2.18 to 2.82 mg/L, were consistently higher than WHO recommendations. Elevated BOD signals a significant concentration of biodegradable organic matter, which exerts oxygen stress on groundwater, potentially compromising ecosystem stability. Conversely, the Chemical Oxygen Demand (COD), ranging between 4.36 and 5.64 mg/L, remained within acceptable limits. COD provides an indication of oxidizable organic and inorganic substances; hence, the findings suggest moderate contamination levels that may not pose immediate hazards but still warrant monitoring.

The ionic dominance pattern for cations was established as $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+ > \text{Mn}^{2+} > \text{Fe}^{2+}$, revealing a clear prevalence of alkaline earth metals over alkali metals. Calcium (44.00-140.00 mg/L) and magnesium (26.73-85.05 mg/L) were consistently elevated, with only borehole B meeting the recommended WHO limit of 7.50 mg/L for cal-

cium. The persistently high concentrations of Ca^{2+} and Mg^{2+} are reflective of aquifer material dissolution, most likely derived from carbonate and silicate mineral breakdown facilitated by groundwater CO_2 . These high values contribute significantly to hard water characteristics, which manifest as scale deposition in household pipes and industrial boilers, thereby raising concerns regarding water suitability for domestic and industrial use without softening [24, 27].

Sodium (11.50-29.90 mg/L) and potassium (6.32-11.34 mg/L) levels were all comfortably below WHO thresholds, posing minimal risk to human health and irrigation. However, manganese concentrations (0.25-0.63 mg/L) exceeded permissible limits at borehole C, highlighting localized enrichment, possibly due to reducing geochemical conditions that promote Mn dissolution. Likewise, iron concentrations (0.32-0.38 mg/L) surpassed WHO standards in all boreholes. This elevated iron presence is strongly linked to the ferruginous Benin Formation sands, rich in minerals such as hematite, limonite, and goethite, which release Fe^{2+} into solution during weathering and leaching [11, 16]. The consequences of excess iron include discoloration of water, metallic taste, and clogging of borehole pumps.

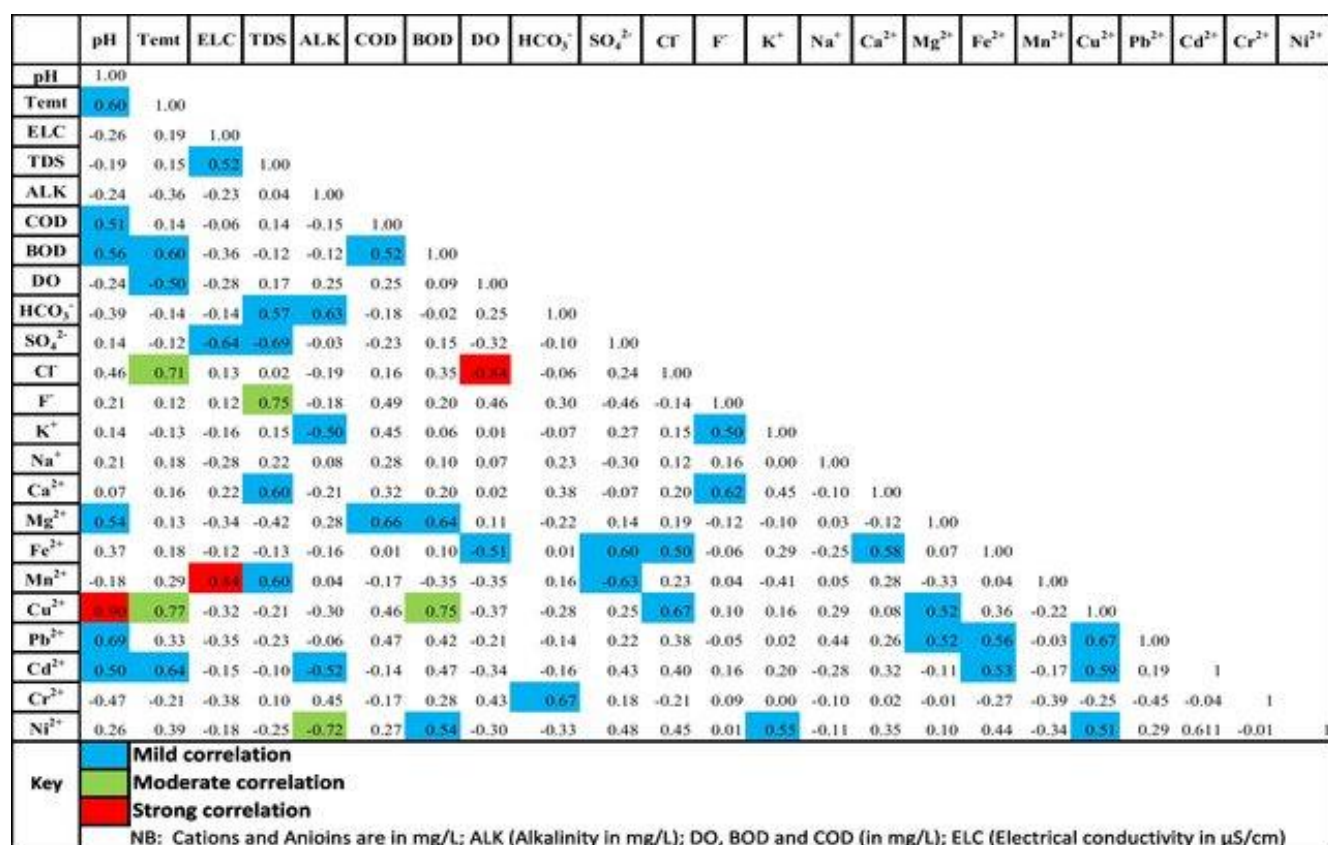


Figure 4. Distribution of the physicochemical parameters in the water samples.

Collectively, the hydrochemical evaluation depicts a groundwater system that is largely fresh, mildly acidic to

neutral, with low mineralization, but exhibiting elevated hardness and trace metal concentrations. The observed water

chemistry points to dominant geogenic controls, particularly aquifer-rock interactions, with limited anthropogenic impact. While most parameters fall within WHO and EPA standards, elevated calcium, magnesium, iron, and manganese levels may impair domestic and industrial usability unless corrective treatment measures such as aeration, softening, or filtration are applied. From a resource management perspective, the study underscores the need for integrated hydrochemical monitoring. The high hardness index suggests a need for pre-treatment for household consumption, while the elevated Fe and Mn levels necessitate removal to prevent long-term health and infrastructural challenges. However, the low EC and TDS values provide reassurance that the aquifers remain relatively unpolluted, retaining their strategic importance as dependable groundwater sources in the region. The percentage distribution of these parameters is illustrated in Figure 4, providing a visual representation of ion concentrations across the sampled boreholes.

4. Conclusion

This study has comprehensively demonstrated the value of integrating 2D Electrical Resistivity Tomography (ERT) with Geographic Information Systems (GIS), remote sensing, and geospatial tools in delineating subsurface zonation and assessing groundwater potential in Ikot Abasi, Nigeria. The application of Vertical Electrical Sounding (VES) surveys provided critical quantitative insights into the geological framework, aquifer geometry, and hydrogeological dynamics of the area, while hydrochemical analysis established the quality and potability status of the groundwater resources. The results of the resistivity investigations highlighted clear lithological contrasts and aquifer variability across the study area. Apparent resistivity values, aquifer depths, thicknesses, and transmissivity parameters were diagnostic of heterogeneous groundwater potential zones. Shallow aquifers with limited storage were observed at sites such as VES 1 and VES 7, where clayey formations dominated, restricting groundwater movement. By contrast, deeper and thicker aquifer units were delineated at VES 3, VES 4, VES 9, and VES 12, with high transmissivity values suggesting zones of substantial groundwater accumulation and sustainable extraction potential. The longitudinal conductance and transverse resistance indices confirmed the protective capacity of subsurface formations, particularly within VES 9 to VES 12, where aquifer materials displayed enhanced resistance to contamination compared to the more vulnerable zones delineated in VES 1 to VES 8.

Hydrochemical evaluation of groundwater samples further strengthened the interpretation by revealing that, although most parameters were within World Health Organization (WHO) permissible limits, notable exceptions exist. Elevated Biochemical Oxygen Demand (BOD) values point to organic matter influence, while high concentrations of calcium, magnesium, and iron suggest geogenic enrichment, consistent

with the dissolution of carbonate minerals and the ferruginous composition of the Benin Formation. The excess iron and manganese content were particularly problematic, as they not only impair water aesthetics and infrastructure but also reduce its suitability for direct human consumption. Consequently, the Water Quality Index (WQI) categorized the groundwater as unsuitable for direct use without treatment, emphasizing the necessity for softening, aeration, and filtration before distribution for domestic or industrial purposes.

Overall, the integration of geophysical, geospatial, and hydrochemical datasets proved highly effective in delineating groundwater-bearing formations, assessing aquifer protective capacities, and identifying potential contamination pathways. This multidisciplinary approach provides a robust framework for groundwater exploration and resource management in sedimentary environments, where lithological heterogeneity and anthropogenic pressures complicate hydrogeological assessments.

In conclusion, the findings of this study not only enhance the scientific understanding of groundwater occurrence in Ikot Abasi but also provide practical implications for sustainable groundwater development. The study underscores the importance of careful borehole siting in zones of high transmissivity and protective capacity, coupled with appropriate water treatment interventions to address hardness and elevated trace metals. Furthermore, the outcomes highlight the need for long-term groundwater monitoring, including the deployment of 3D ERT and time-series remote sensing techniques, to track seasonal and anthropogenic influences on groundwater systems. Such integrative strategies are critical for safeguarding water security, improving community resilience, and promoting sustainable development in line with the United Nations Sustainable Development Goals (SDGs).

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Author Contributions

Mfoniso Udofia Aka: Formal Analysis, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing

Okechukwu Ebuka Agbasi: Data curation, Formal Analysis Software, Resources, Writing – review & editing
Johnson Cletus Ibuot: Investigation, Methodology, Validation, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

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